The Driving Visual Field and a History of Motor Vehicle Collision Involvement in Older Drivers: A Population-Based Examination

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Structured Abstract

Purpose: We designed a visual field test focused on the field utilized while driving to examine associations between field impairment and motor vehicle collision involvement in 2,000 drivers ≥70 years old.

Methods: The "driving visual field test" involved measuring light sensitivity for 20 targets in each eye, extending 15° superiorly, 30° inferiorly, 60° temporally and 30° nasally. The target locations were selected on the basis that they fell within the field region utilized when viewing through the windshield of a vehicle or viewing the dashboard while driving. Monocular fields were combined into a binocular field based on the more sensitive point from each eye. Severe impairment in the overall field or a region was defined as average sensitivity in the lowest quartile of sensitivity. At-fault collision involvement for five years prior to enrollment was obtained from state records. Poisson regression was used to calculate crude and adjusted rate ratios examining the association between field impairment and at-fault collision involvement.

Results: Drivers with severe binocular field impairment in the overall driving visual field had a 40% increased rate of at-fault collision involvement (RR 1.40, 95%CI 1.07–1.83). Impairment in the lower and left fields was associated with elevated collision rates (RR 1.40 95%CI 1.07–1.82 and RR 1.49, 95%CI 1.15–1.92, respectively), whereas impairment in the upper and right field regions was not.

Conclusions: Results suggest that older drivers with severe impairment in the lower or left region of the driving visual field are more likely to have a history of at-fault collision involvement.

Driving a vehicle takes place in a complex and ever-changing roadway environment where peripheral vision is relied upon for many component tasks such as lane-keeping, avoiding obstacles, and passing through intersections. Ocular and neurological conditions that cause peripheral vision loss, such as glaucoma and cerebrovascular accident, are more common in older adults,[1, 2] and even in the absence of these conditions, older adults have reduced light sensitivity in the peripheral visual field compared to younger adults.[3] Two previous population based studies suggest that visual field impairment is associated with an increased risk of motor vehicle collision (MVC) involvement.[4, 5] In a California study of 10,000 drivers aged ≥ 16 years old,[4] a visual field screening test showed that drivers with severe field loss in both eyes had a two-fold increased crash rate compared to drivers with normal fields; most of the drivers with severe binocular field loss were older adults. A population-based study of older drivers in Maryland[5] reported that those who missed ≥ 20 points on a 96-point binocular visual field screening test were 30% more likely to be crash involved in subsequent years. In addition, the study found that the lower visual field may be more relevant than other regions of the field for identifying high risk drivers. Finally, studies of drivers with visual field impairment due to glaucoma or homonymous hemianopia or quadrantanopia have suggested they have increased MVC risk. [6-9]

However, several other large sample studies of older drivers have reported no association between MVC involvement and visual field loss.[10-12] The lack of agreement among studies may stem from differences in methodological approaches. Specifically, some studies used a single-intensity-target screening protocol,[4, 5] while others measured thresholds at each test target location.[6, 7, 12] Some studies evaluated the visibility of targets extending to 60° eccentricity in many directions,[4, 5 9, 12] while others focused only on the horizontal field,[10] or the central field

(24-30° radius).[6, 7] Some studies have combined the visual fields in each eye to create a binocular field,[5, 8, 12] or measured the field while viewing binocularly [9, 10] while others presented field results in terms of the eye with better or worse sensitivity.[6, 7] Studies have also varied in terms of the characteristics of their driving sample population, including those seeking license renewal at motor vehicle departments,[4, 10] with specific medical problems,[6, 7, 9] or having high MVC rates compared to the general population.[12] In addition, factors that may confound the association between visual field impairment and crash risk were not always taken into account in previous research.[4]

Here we report the results of a population-based study of older drivers that used a novel visual field testing approach. In previous research on visual field impairment and older driver safety, the visual field tests utilized were primarily those designed to screen for or manage ocular disease, rather than being based on the visual and human factor characteristics of the driving task. In the present study we have implemented a visual field test specifically focused on the visual field area utilized when viewing through the windshield of a vehicle or when viewing the dashboard while driving.[13] The objective of this population-based study was to examine the association between visual field impairment as assessed by this "driving visual field" test and a history of at-fault MVC collisions among older drivers.

Methods

This study was approved by the Institutional Review Board of the University of Alabama at Birmingham. As described in detail elsewhere,[14] the source population for the study consisted of adults aged ≥ 70 years old who resided in north central Alabama. Potential participants were randomly identified from contact information available through a list of persons in this geographic region obtained from a direct marketing company. Potential participants were randomly selected from the final list and contacted by letter that was followed up by a phone call. Individuals who had an Alabama license and had driven within the last three months, were ≥ 70 years old, and spoke English were invited for a single study visit. Participants were enrolled between October 2008 and August 2011. The final sample consisted of 2,000 drivers.

A trained interviewer confirmed demographic information (age, gender, race/ethnicity) and administered a general health questionnaire about the presence versus absence of chronic medical conditions (i.e., "has a doctor ever told you that you have . . .").[12] The mini-mental state examination (MMSE) was administered to estimate general cognitive status.[15] Binocular visual acuity was assessed using the Electronic Visual Acuity (EVA) system,[16] and expressed as log minimum angle resolvable (logMAR). Testing was undertaken with the habitual refractive correction used when driving; that is, participants wore whatever spectacles or contact lenses they normally wear when driving. Contrast sensitivity was measured using the Pelli-Robson Contrast Sensitivity chart[17] and scored using the letter-by-letter method and expressed as log sensitivity.[18] Visual processing speed under divided attention conditions was examined using the UFOV subtest 2 (Visual Awareness Research Group, Punta Gorda, FL).[19] An estimate of driving exposure (i.e., miles driven in a typical week) was generated through administration of the Driving Habits Questionnaire.[20]

Visual field sensitivity was assessed for each eye separately using a custom test designed for the Humphrey Field Analyzer (HFA) Model II-i (Carl Zeiss Meditec, Dublin CA). The selection of test target locations were based on the visual field area relevant to when a driver gazes toward the roadway environment through a vehicle's windshield[13] or at the vehicle's dashboard. Figure 1 is an example of the driver's view through the windshield and side windows of a typical vehicle; this view is the widest possible panoramic view afforded as the driver's head turns from one side of the roadway to the other. This example illustrates that the potential visibility available from the driver's vantage point in the vehicle consists of a horizontally-extended, quasi-rectangular view of the roadway environment, which also includes the dashboard. Although there will be individual variability among vehicles in the exact dimensions of this "visibility window", the dimensions of this view are quite similar across vehicles.[13] In constructing the driving visual field test for each eye, we selected test target locations in the HFA that covered the widest possible horizontal extent of the field that could be tested for that eye (up to 60°), with targets extending out to 15° superiorly and 30° inferiorly, consistent with a previous analysis of the driving visual field and our own measurements of a series of vehicles.[13] The number of test target locations selected for the test was influenced by our desire that the test take no longer than approximately 5 minutes per eye. Figure 2 displays the locations of the 20 test targets for each eye. Light sensitivity was measured in each eye using the HFA's full-threshold procedure using a white stimulus-size III target at each of the 20 monocular visual field locations. Best correction for the HFA test distance was provided with trial lenses when testing targets within the 30° radius field, which were removed for targets outside the 30° radius field. The duration of the test was approximately five minutes per eye.

Since the driving task is performed using both eyes together, the monocular visual fields from each participant were combined to form a binocular field consisting of 21 points spanning 60˚ to the right and left, 15˚ to the superior field, and 30˚ to the interior field (Figure 2). The sensitivity at each test location was defined by the more sensitive point (higher value) of the two eyes.[21] Where sensitivity was tested in one eye only (there was one such test location for each eye at 60° temporal on the horizontal meridian), sensitivity in that eye defined the sensitivity of the point in the binocular field. Test locations in the binocular visual field were grouped into various regions as follows, where sensitivity for that region was expressed as mean sensitivity (non-age-adjusted) for all test targets in that region: the overall field that included all test points; the upper field that included all points above the horizontal meridian; all points along the horizontal meridian; the lower field that included all points below the horizontal meridian; the left visual field that included all points to the left of the vertical meridian; all points along the vertical meridian; and the right visual field that included all points to the right of the vertical meridian. Quartiles for the average sensitivity (dB) for each region were determined. A participant was defined as having severe visual field impairment in that region if their average sensitivity was in the lowest quartile of sensitivity (worse sensitivity). As such, participants could have visual field impairment in more than one region. We also computed quartiles of sensitivity for each test target; participants were defined as having impaired sensitivity for that test target if they fell into the lowest quartile.

Information about participants' motor vehicle collision involvement occurring within five years prior to enrollment was obtained through accident reports made available to the study by the Alabama Department of Public Safety. At-fault status was indicated on the report by the police officer at the scene who investigated the collision.

Statistical Analysis: Demographic characteristics, visual function, cognitive status, and annual mileage were described for the overall sample. Poisson regression models were used to calculate crude and adjusted rate ratios (RR) and 95% confidence intervals (CI) to examine the association between visual field impairment based on the binocular visual field and at-fault motor vehicle collision involvement. The models used a log link function and accounted for the natural log of the annual miles driven as an offset. Adjusted models took into account age, gender, race, visual acuity, contrast sensitivity, visual processing speed, mental status, and number of chronic medical comorbidities. Separate models were used to calculate the RR for the overall visual field and the region-specific fields as defined above. A p-value of <0.05 (two-tailed) was used to define statistical significance.

Results

Eligible persons who enrolled were on average one year younger (77 years old) than those who declined participation (78 years old) ($p<0.0001$) and were also more likely to be male ($p<0.0001$). Approximately 75% of the sample was between the ages of 70 and 79 years and the remaining were aged 80 years and older (Table 1). Slightly over half were female. Approximately 18% were African American and 82% were White, which is consistent with the demographics of the recruitment area. Almost half of the sample had three or fewer medical conditions. The vast majority (98%) of participants had MMSE scores in the non-demented range (≥ 24). Just over half the sample (57%) had binocular visual acuity of 20/20 of better and more than 90% of the drivers had a visual acuity of 20/40 or better. The remaining 9% had visual acuity in the 20/50 to 20/200 range, though most were between 20/50 and 20/100. Eighty-five percent of the sample had contrast sensitivity scores of 1.5 log units or better. Visual processing speed was in the normal range (<150 ms) for 56% of the sample. Drivers on average reported driving 9,528 miles per year. Fourteen percent (n=280) of the drivers had been involved in one or more at-fault MVCs in the prior five years.

Table 2 presents the crude RR comparing retrospective at-fault MVC rates between participants with and without visual field impairment. RRs are also presented after adjusting for age, gender, race, visual acuity, contrast sensitivity, visual processing speed, mental status score and number of medical conditions. We will focus on adjusted associations in describing the results. When average sensitivity across all test targets in the overall visual field is considered, drivers with field impairment had a 40% increased rate of at-fault MVC compared to those with average sensitivity in the three upper quartiles of sensitivity. Although impairment in the upper field was not related to an increased rate of at-fault MVC, impairment along the horizontal meridian and lower field were associated with a 31% and 40% increased rate of collision involvement, respectively. When we restricted this analysis to the 5 targets along the +15° horizontal meridian in the superior field and the 5 targets along the -15° meridian in the inferior field, the rate ratio for the superior field was still not significant (RR 1.17, 95% CI 0.86 – 1.57), and the rate ratio for the inferior field remained significant, increasing slightly (RR 1.46, 95% CI 1.12 – 1.90). Considering the laterality of the field, although impairment in the left side of the field was associated with a 49% increased rate of collision involvement, impairment in the right side of the field and the vertical meridian locations were unrelated to collision involvement. When a count of the number of test targets for each participant was generated, those participants with ≥ 7 test targets in the lowest quartile of sensitivity had a 51% higher rate of at-fault MVCs compared to those with no targets falling into the lowest quartile.

Discussion

Older drivers with severe sensitivity impairment in the area of the visual field used to view the roadway environment and dashboard had an approximately 40% higher rate of at-fault MVC involvement compared to those with no or less field impairment. When the driving visual field was parsed into various regions, an interesting pattern emerged. The areas of the field along the horizontal meridian region and lower, and to the left side of the visual field were positively associated with at-fault MVC involvement, whereas the upper and right hand fields did not demonstrate an association. The associations with left side and lower field deficits were modest (RRs ranging from 1.31 – 1.49), however they remained even after adjusting for a variety of potentially confounding variables such as other forms of vision impairment, mental status, and medical comorbidities.

A novel feature of this older driver study is the use of a visual field test that represents the extent of the visual world that is visible from the driver's visual vantage point.[13] Our driving visual field test does not waste time measuring light sensitivity in areas of the field outside the vehicle that are obscured by the vehicle's interior (e.g., ceiling), since these areas are not used by the driver in detecting obstacles and events in the roadway environment or in interacting with the dashboard. Most previous studies on visual field impairment and older driver safety have utilized visual field protocols that were originally designed for the detection and management of ocular disease, such as glaucoma (e.g., HFA 24-2, 30-2, 96-point screening test), and some used age-adjusted thresholds which are not appropriate for understanding driving.[5-7, 12] Thus while these visual field tests designs may be suitable for ocular disease detection and management, they are not motivated by functional driving performance considerations from a human factors perspective.

Our results suggest that impairment along the horizontal meridian and lower into the inferior visual field is particularly germane to understanding crash risk in older drivers since the associations between impairment and collision involvement were preferentially located in this region of the visual field rather than the superior field. The importance of the lower periphery in understanding crash risk in older drivers was first reported by Rubin et al.,[5] however in that study a crude single intensity screening test was used, rather than a full threshold determination procedure as employed here. Loss in the lower visual field has also been associated with other types of mobility problems in older adults such as reduced postural stability,[22] slower “timed up and go” performance,[23] weaker lower limb strength,[23] lower self-reported physical activity,[23] slower walking speed,[24] and increased falls risk.[25] Interestingly, some of these adverse mobility outcomes have also been associated with increased MVC risk.[26-28] The precise mechanisms that underlie the association between lower field impairment and MVC are not clear. One possibility, albeit speculative, is that since the lower field provides obstacle and event information immediately in front of the vehicle, it informs the driver about physical features of the roadway environment that are the most relevant in terms of avoiding an immediate collision risk. Thus, loss of sensitivity in this region of the field could be highly detrimental to driver safety.

Recently Glen et al. (Glen FC, et al. *IOVS* 2014;55: ARVO E-Abstract 3009) described a study on the relationship between performance in the Hazard Perception Test (HPT) and visual field impairment in the upper versus lower visual field which was simulated in normally sighted drivers. The HPT is used by some jurisdictions (e.g., United Kingdom, Australia) in the licensure process to assess the applicant’s ability to detect hazards (defined as events that cause the driver to take action). Simulated defects in the upper field more strongly hampered HPT performance than did simulated defects in the lower field. At face value our results indicating the greater relevance of lower field defects to driver safety may seem contradictory to the findings of Glen et al. However it is important to consider the HPT’s design. Most of the potential hazards in this test are events and objects at a distance further down the road, not immediately in front of the vehicle, and thus the hazards are positioned in the upper visual field. Thus in this sense it is not surprising that detection of those potential hazards would be more deleteriously impacted by upper field defects than lower field defects. In our study, our dependent measure was not hazard detection (which is but one aspect of driving performance), but rather MVC involvement, which is a direct metric for driver safety. If the goal is to design a visual field test that can be used to make recommendations about driver safety, then studies using at-fault MVCs as the outcome of interest seem more germane for guiding visual field screening test designs for licensure determinations.

Our results also suggest that impairment on the left side of the visual field in older drivers is linked to increased risk for MVC involvement. In a country such as the United States where vehicles are driven on the right side of the road, monitoring traffic and lane markings in the oncoming lane to the left of one's vehicle is a crucial skill for avoiding potential collisions. Thus, impairments in the left visual field could hamper road safety. It would be interesting to determine if, conversely, impairment on the right side of the field results in increased MVC vulnerability for drivers in countries where vehicles are driven on the left side of the road (e.g., United Kingdom, Republic of Ireland, Australia, India, Japan).

In 40 of 50 states in the United States, there is a periodic vision re-screening policy in place that requires drivers to demonstrate that they can pass the visual acuity screening standard in order to remain licensed (in most states the standard is in the 20/30 - 20/40 range).[29] This essentially makes it difficult to study vision impairment and driver safety in these states since those who have vision impairment are likely to be denied licensure and thus become non-drivers and are not represented in the older driver studies that examine associations between vision impairment and MVC involvement. However, in Alabama, where this study took place, there is no visual acuity re-screening performed at subsequent license renewals. That is, the vast majority of older drivers in Alabama last took a visual acuity screening test when they applied for licenses as teenagers or young adults, a time in life when the vast majority of the population have a visual acuity of 20/60 or better. Alabama also has a visual field standard for licensure (the visual field must be at least 110° across the horizontal meridian), however, a visual field test is not performed at license application nor at subsequent license renewals.[29] This means older drivers in Alabama who do not meet the vision standards (visual acuity or visual field standards) are not necessarily removed from the road through licensure screening programs, and thus are represented in study samples on older driver safety since they are still drivers. Thus, positioning this study in Alabama offers a relatively unique opportunity to study driver safety in persons with impaired vision.

Other study strengths include the use of a large, population-based sample of older drivers thus facilitating generalizability to the general population of drivers in this age range. Rather than using a visual field screening test with an arbitrary cut-point for pass-fail and a single intensity test target as in previous population-based studies,[4, 5] we utilized a full-threshold measurement procedure to estimate threshold and subsequently to define impairment. We adjusted for a number of important factors that may confound the association between visual field impairment and crash involvement such as other types of vision impairment (acuity, contrast sensitivity, visual processing speed), medical comorbidities, and mental status. The pattern of results was unchanged even after removing all participants from the analysis who had ≥ 20% trials with fixation losses. The current study focused on MVCs that were considered to be the fault of the driver, rather than MVCs regardless of fault, since they are more likely to be tied to the driver's functional characteristics than collisions that are clearly not the fault of the driver.[30]

Limitations must also be acknowledged. Analyses were based on a cross-sectional study design where visual field impairment was evaluated in terms of its association with crashes occurring during the previous 5 years. If individuals with visual field impairment are more likely to die or cease driving as compared to those without field impairment, then the remaining pool of drivers will show a lower frequency of visual field impairment. We would expect this to bias the results toward the null, therefore any true association would be underestimated. We will ultimately be able to address the prospective question since the 2,000 older drivers in this sample are being followed for three years subsequent to enrollment in order to examine the relationship between visual field impairment at baseline and future MVC involvement. It also remains to be determined if our findings are generalizable to jurisdictions where vehicles are driven on the left side of the road. Driving exposure (miles driven) was measured by self-report, not objectively, however, previous studies have suggested good agreement between self-report and actual mileage. [31, 32]

In conclusion, this study suggests that severe binocular impairment in the visual field area subserving the roadway environment – the "driving visual field" – elevates the rate of MVC involvement in older adults, even after other potentially confounding factors are taken into account. By severe impairment we mean light sensitivity in the lowest quartile compared to other older drivers. Impaired visual field areas most strongly related to elevated MVC rates in this study are along the horizontal meridian and lower and the left-hand portions of the field. This implies that parsimonious visual field screening strategies for identifying at-risk older drivers should be most efficiently targeted at these areas of the field. Prospective study of this sample will examine to what extent assessment of the driving visual field can be useful in identifying older drivers at risk for future MVCs and whether a brief screening test focused on selected field areas could be practically useful in monitoring driver safety in older drivers.

References

1. Friedman DS, Wolfs RC, O'Colmain BJ, et al. Prevalence of open-angle glaucoma among adults in the United States. *Arch Ophthalmol.* 2004;122:532-538.
2. Williams GR. Incidence and characteristics of total stroke in the United States. *BMC Neurol.* 2001;1:2.
3. Brenton RS, Phelps CD. The normal visual field on the Humphrey field analyzer. *Ophthalmologica.* 1986;193:56-74.
4. Johnson CA, Keltner JL. Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Arch Ophthalmol.* 1983;101:371-375.
5. Rubin GS, Ng ES, Bandeen-Roche K, Keyl PM, Freeman EE, West SK. A prospective, population-based study of the role of visual impairment in motor vehicle crashes among older drivers: the SEE study. *Invest Ophthalmol Vis Sci.* 2007;48:1483-1491.
6. McGwin G, Xie A, Mays A, et al. Visual field defects and the risk of motor vehicle collisions among patients with glaucoma. *Invest Ophthalmol Vis Sci.* 2005;46:4437-4441.
7. Haymes SA, LeBlanc RP, Nicolela MT, Chiasson LA, Chauhan BC. Risk of falls and motor vehicle collisions in glaucoma. *Invest Ophthalmol Vis Sci.* 2007;48:1149-1155.
8. McGwin G Jr, Huisingh C, Jain SG, Girkin CA, Owsley C. Binocular visual field impairment in glaucoma and at-fault motor vehicle collision risk. *J Glaucoma.* in press.
9. McGwin G Jr, Wood JM, Owsley C. Motor vehicle collision involvement among persons with hemianopia and quadrantanopia. Under review.
10. Decina LE, Staplin L. Retrospective evaluation of alternative vision screening criteria for older and younger drivers. *Accid Anal Prev.* 1993;25:267-275.

11. Hu PS, Trumble D, Lu A. Statistical relationships between vehicle crashes, driving cessation, and age-related physical or mental limitations: Final summary report. National Highway Traffic Safety Administration, US Departmenet of Transportation. Washington DC; 1997.

12. Owsley C, Ball K, McGwin G, Jr., et al. Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA.* 1998;279:1083-1088.

13. Vargas-Martin F, Garcia-Perez MA. Visual fields at the wheel. *Optom Vis Sci.* 2005;82:675-681.

14. Owsley C, McGwin G Jr, Searcey K. A population-based examination of the visual and ophthalmological characteristics of licensed drivers ages 70 years old and over. *J Gerontology A Biol Sci Med Sci.*2013;68:567-573.

15. Folstein MF, Folstein SW, McHugh PR. "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975;12:189-198.

16. Beck RW, Moke PS, Turpin AH, et al. A computerized method of visual acuity testing: adaptation of the early treatment of diabetic retinopathy study testing protocol. *Am J Ophthalmol.* 2003;135:194-205.

17. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. *Clin Vis Sci.* 1988;2:187-199.

18. Elliott DB, Bullimore MA, Bailey IL. Improving the reliability of the Pelli-Robson contrast sensitivity test. *Clin Vis Sci.* 1991;6:471-475.

19. Edwards JD, Ross LA, Wadley VG, et al. The useful field of view test: Normative data for older adults. *Arch Clin Neuropsychol.* 2006;21:275-286.

20. Owsley C, Stalvey B, Wells J, Sloane ME. Older drivers and cataract: Driving habits and crash risk. *J Gerontology A Biol Sci Med Sci.* 1999;54A:M203-M211.

21. Nelson-Quigg JM, Cello K, Johnson CA. Predicting binocular visual field sensitivity from monocular visual field results. *Invest Ophthalmol Vis Sci.* 2000;41:2212-2221.

22. Black AA, Wood JM, Lovie-Kitchin J, Newman B. Visual impairment and postural sway among older adults with glaucoma. *Optom Vis Sci.* 2008;85:489-497.

23. Black AA, Wood JM, Lovie-Kitchin JE. Inferior visual field reductions are associated with poorer functional status among older adults with glaucoma. *Ophthalmic Physiol Opt.* 2011;31:283-291.

24. Turano KA, Broman AT, Bandeen-Roche K, et al. Association of visual field loss and mobility performance in older adults: Salisbury Eye Evaluation Study. *Optom Vis Sci.* 2004;81:298-307.

25. Black AA, Wood JM, Lovie-Kitchin JE. Inferior field loss increases rate of falls in older adults with glaucoma. *Optom Vis. Sci.* 2011;88:1275-1282.

26. Huisingh C, McGwin G Jr, Orman KA, Owsley C. Frequent falling and motor vehicle collision involvement of older drivers. *J Am Geriatr Soc.* 2014;62:123-129.

27. Marottoli RA, Cooney Jr. LM, Wagner DR, Doucette J, Tinetti ME. Predictors of automobile crashes and moving violations among elderly drivers. *Ann Intern Med.* 1994;121:842-846.

28. Sims RV, McGwin G Jr, Pulley LV, Roseman JM. Mobility impairments in crash-involved older drivers. *J Aging Health.* 2001;13:430-438.

29. Prevent Blindness. State Vision Screening and Standards for License to Drive. Accessed 07/01/14. http://lowvision.preventblindness.org/daily-living-2/state-vision-screening-and-standards-for-license-to-drive

30. Owsley C, Wood JM, McGwin G Jr. A roadmap for interpreting the literature on vision and driving. Under review.

31. Blanchard RA, Myers AM, Porter MM. Correspondence between self-reported and objective measues of driving exposure and patterns in older drivers. *Accid Anal Prev* 2010;42:523-529.

32. Murakami E, Wagner DP. Comparison between computer-assisted self-interviewing using GPS with retrospective trip reporting using telephone interviews. Washington DC: Federal Highway Administration, U.S. Department of Transportation; 1997.

Table 1. Characteristics of the study sample (N=2000)

Characteristic	n (%) or mean (SD)
Age, years	
70 - 79	1433 (72%)
80 - 89	527 (26%)
90 - 98	40 (2%)
Gender	
Men	1130 (57%)
Women	870 (44%)
Race	
African American	351 (18%)
White	1640 (82%)
Other	9 (<1%)
No. of medical co-morbidities	
0 – 1	226 (11%)
2 – 3	721 (36%)
4 – 5	694 (35%)
> 5	359 (18%)
Mental status, MMSE score	
24 - 30	1953 (98%)
17 - 23	45 (2%)
1 - 16	2 (<1%)
Visual acuity (OU)	
20/20 or better	1132 (57%)
Worse than 20/20 to 20/40	705 (35%)
Worse than 20/40 to 20/100	159 (8%)
Worse than 20/100 to 20/200	2 (<1%)
Contrast sensitivity (OU)	
<1.5	132 (7%)
≥1.5	1867 (93%)
Visual processing speed (ms)	
<150	1125 (56%)
150-350	653 (33%)
>350	221 (11%)
Overall visual field sensitivity (dB)	23.8 (3.2)
≤ 22.5 (worse)	496 (25%)
22.6-24.2	491 (25%)
24.3-25.6	507 (25%)
≥ 25.7 (better)	506 (25%)
Annual mileage	9527.7 (9420.2)
No. of at-fault MVCs	
0	1732 (87%)
1	235 (12%)
2 or more	33 (2%)

Table 2. Association between binocular visual field impairment and rates of at-fault crashes for the overall field, by region in the field, and by the number of test targets that were impaired

	Crude RR (95% CI)	Adjusted RR[1] (95% CI)	p-value
Overall field	1.83 (1.45-2.33)	1.40 (1.07-1.83)	0.014
Upper field	1.57 (1.23-2.01)	1.10 (0.83-1.44)	0.51
Horizontal meridian	1.78 (1.40-2.26)	1.31 (1.00-1.72)	0.048
Lower field	1.85 (1.46-2.34)	1.40 (1.07-1.82)	0.014
Left side	1.96 (1.55-2.48)	1.49 (1.15-1.92)	0.0024
Vertical meridian	1.68 (1.32-2.13)	1.26 (0.97-1.64)	0.078
Right side	1.64 (1.29-2.10)	1.16 (0.88-1.53)	0.28
Number of test target locations with impairment			
0 (reference)	1.0	1.0	
1-2	0.83 (0.59-1.18)	0.77 (0.54-1.10)	0.15
3-6	1.43 (1.05-1.95)	1.19 (0.86-1.64)	0.29
7-21	2.13 (1.59-2.86)	1.51 (1.08-2.12)	0.016

[1] Adjusted for age, gender, race, visual acuity, contrast sensitivity, MMSE, # of medical conditions, and Useful Field of View
All models were adjusted for annual mileage.

Figure 1. Driver's view through the windshield and side windows of a vehicle; this view is the widest possible panoramic view from the driver's vantage point as the driver's head turns from one side of the roadway to the other.

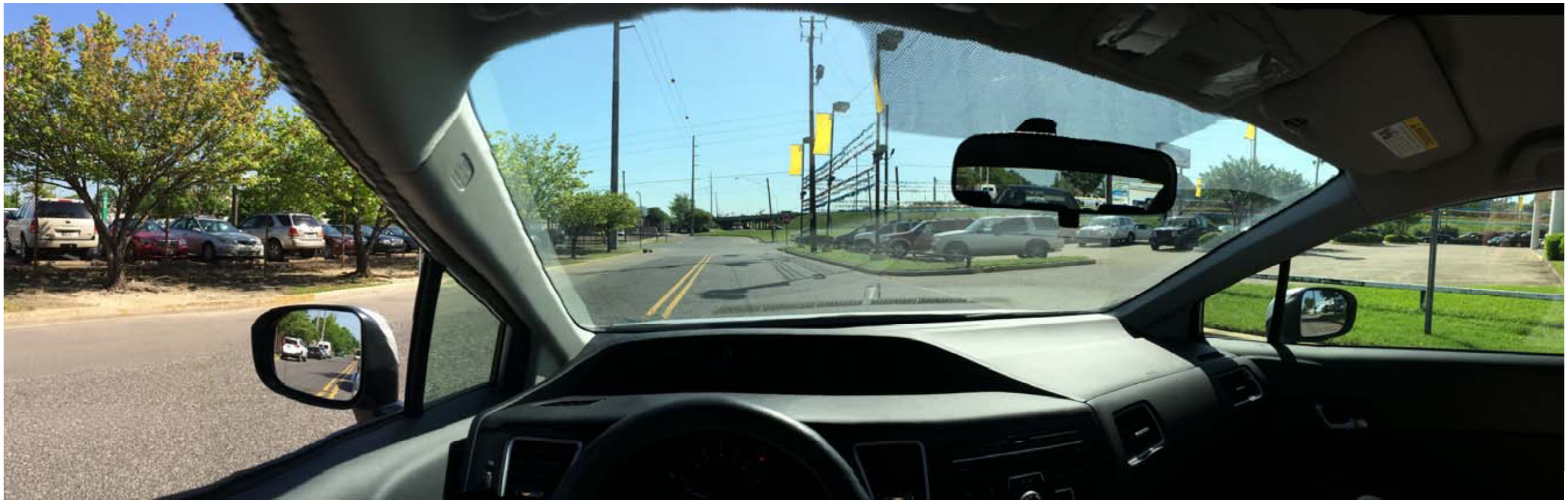
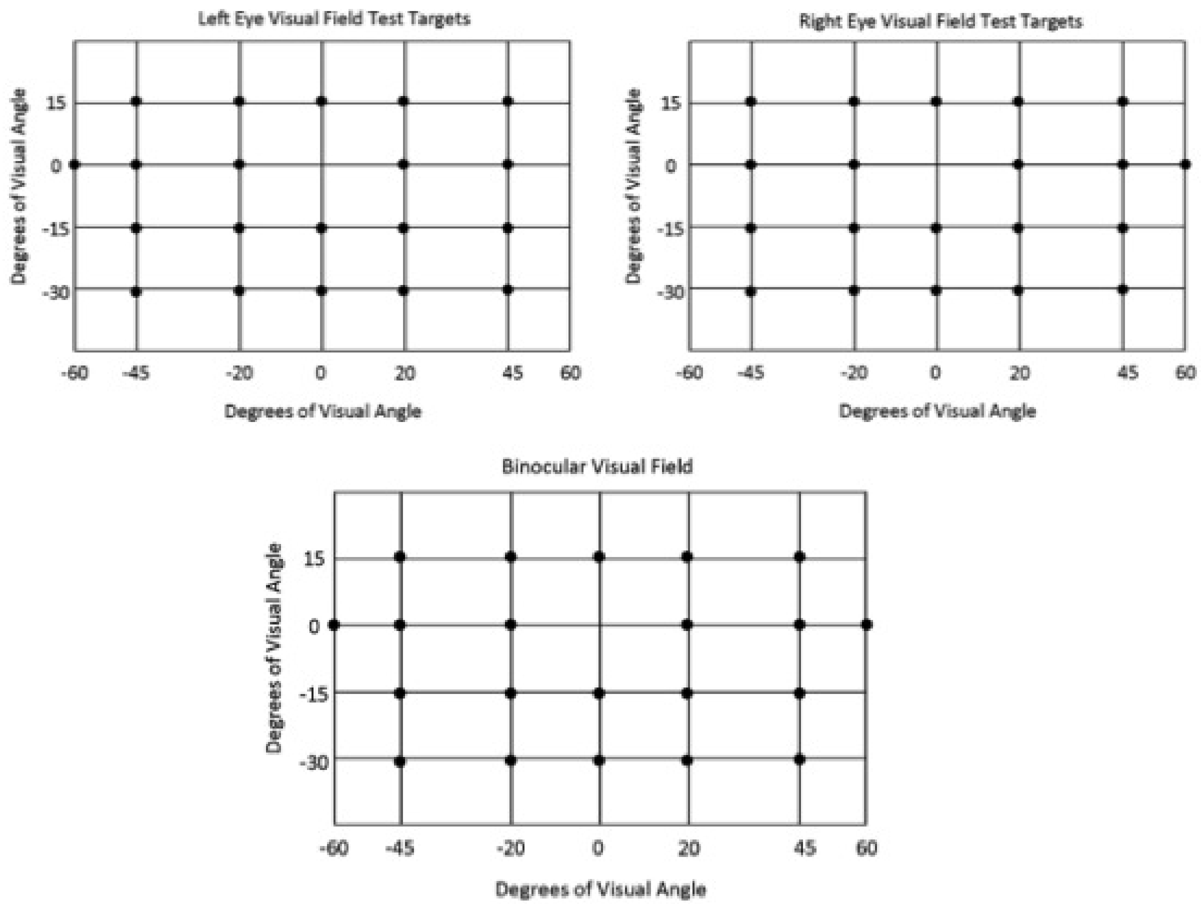


Figure 2. Test target locations for visual field of the left eye, of the right eye, and of the binocular visual field



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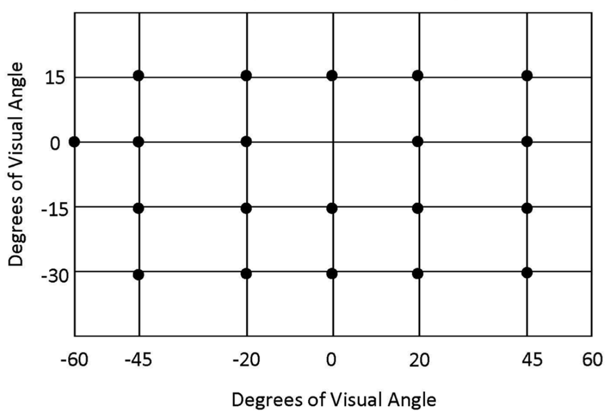
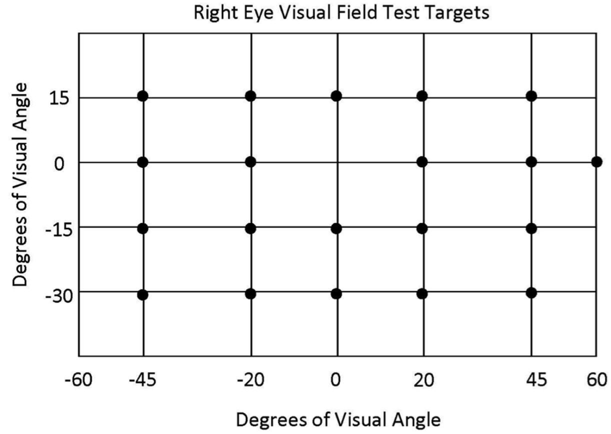
Left Eye Visual Field Test Targets



Right Eye Visual Field Test Targets



Binocular Visual Field